AD-A141 532 QUASI-STEADY STATE MULTI-PLASMA CLOUD CONFIGURATION IN THE IONOSPHERE(U) NAVAL RESEARCH LAB WASHINGTON DC J CHEN ET AL. 20 APR 84 NRL-MR-5302 SBI-AD-E000 565 1/1

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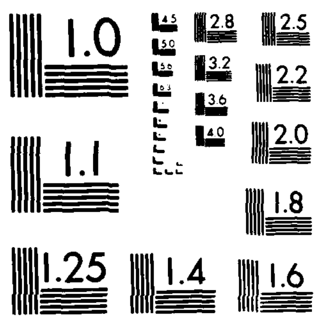

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NRL Memorandum Report 5302

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Quasi-Steady State Multi-Plasma Cloud Configuration in the Ionosphere

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April 20, 1984

This research was supported by the Defense Nuclear Agency under Subtask S99QMXBC, work unit 00102, work unit title "Plasma Structure Evolution," and by the Office of Naval Research.

NAVAL RESEARCH LABORATORY
Washington, D.C.

AD-A141 039

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; distribution unlimited.
2b DECLASSIFICATION/DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S): NRL Memorandum Report 5302	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Research Laboratory; 6b OFFICE SYMBOL (If applicable): Code 4780	7a NAME OF MONITORING ORGANIZATION
6c ADDRESS (City, State and ZIP Code): Washington, DC 20375	7b ADDRESS (City, State and ZIP Code)
8a NAME OF FUNDING/SPONSORING ORGANIZATION: DNA and ONR; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State and ZIP Code): Washington, DC 20305 Arlington, VA 22217	10 SOURCE OF FUNDING NOS.
11 TITLE (Include Security Classification): (See Page ii)	

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT NO.
62715H	RR033-02-44		47-0889-04 47-0883-04

12 PERSONAL AUTHOR(S): J. Chen,* P. Satyanarayana,* and S. L. Ossakow

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Yr., Mo., Day)	15 PAGE COUNT
Interim	FROM 10/83 TO 10/84	April 20, 1984	39

16 SUPPLEMENTARY NOTATION: *Science Applications, Inc., McLean, VA 22102 (Continues)

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB. GR.	Plasma clouds; Steady state theory; F region ionosphere

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

The morphology of a finite array of plasma density enhancements (multi-plasma clouds) in the ionosphere is studied in order to determine the condition under which the system undergoes a quasi-steady state $E \times B$ drift. In such a system, the polarization induced self-electric field inside all the plasma clouds must be essentially equal and uniform. The method of image dipoles previously developed for multi-equatorial spread F bubbles is used to calculate the instantaneous electric field exactly. It is found that, even for small separation distances for which the inter-cloud interaction is significant, the electric field inside the clouds can remain essentially uniform for typical ionospheric plasma cloud parameters so that the multiple plasma clouds drift in unison without changing their geometrical shapes. This constitutes a quasi-steady state configuration. The implications on the behavior of late-time plasma cloud striations are discussed.

20 DISTRIBUTION/AVAILABILITY OF ABSTRACT: UNCLASSIFIED/UNLIMITED X SAME AS RPT. ☐ DTIC USERS ☐	21 ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED	
22a NAME OF RESPONSIBLE INDIVIDUAL: S. L. OSSAKOW	22b TELEPHONE NUMBER (Include Area Code): (202) 767-2723	22c OFFICE SYMBOL: Code 4700

DD FORM 1473, 83 APR EDITION OF 1 JAN 73 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE

11. TITLE (Include Security Classification)

QUASI-STEADY STATE MULTI-PLASMA CLOUD CONFIGURATION IN THE IONOSPHERE

16. SUPPLEMENTARY NOTATION (Continued)

This research was supported by the Defense Nuclear Agency under Subtask S99QMXBC, work unit 00102, work unit title "Plasma Structure Evolution," and by the Office of Naval Research.

CONTENTS

QUASI-STEADY STATE MULTI-PLASMA CLOUD CONFIGURATION IN THE IONOSPHERE

1. INTRODUCTION

It has been observed that kilometer-scale size structures can persist in both barium and nuclear cloud striation phenomena (J. Fedder, W. Chesnut and L. Wittwer, 1980, private communication). Beyond a certain point (late times) after the release of such plasma clouds, the bifurcation of clouds appears to stop and there is a tendency for the striations to drift in unison for as long as they can be seen. In addition, the survival for hours of the kilometer scale structures has been evidenced by propagation studies (Prettie et al., 1977). This observed behavior of ionospheric plasma clouds is often referred to as the "freezing" phenomenon.

Recently, some studies have attempted to understand the apparent observed cessation of the bifurcation process at a scale length of kilometers. Modelling the plasma cloud and ionosphere as a single two-dimensional layer perpendicular to the ambient geomagnetic field ($\underline{B}_o$) including cross-field diffusion due to electron-ion collisions, McDonald et al. (1981) carried out theoretical and numerical simulation studies. They produced a "U" shaped curve representing the minimum striation scale size (a structure's stability against further bifurcation) as a function of the ratio of the integrated Pedersen conductivity of the plasma cloud to the background ionosphere. However, classical electron diffusivity ($\sim$ 1 m^2/sec) produced minimum scale sizes of the order of 10 to 30 m. Consequently, anomalous diffusion ($\sim$ 100 m^2/sec) had to be invoked in order to obtain "freeze-up" of kilometer scale sizes. The work of Ossakow et al. (1981) proposed that including a second level for the background ionosphere (see, for example, Scannapieco et al., 1976) would allow image striations

Manuscript approved January 24, 1984.

to build up and allow the conductivity in a striation to be amplified. This in turn would allow for larger conductivity ratios than if one had just one cloud level, which in turn, could result in kilometer minimum scale sizes by extrapolating the U shaped curve of McDonald et al. (1981) to higher conductivity ratios.

The above studies have sought the possible mechanisms that may be responsible for the apparent cessation of bifurcation associated with the $\underline{E} \times \underline{B}$ gradient drift instability. However, there is another necessary ingredient for the freezing phenomenon. After bifurcation has stopped, the multiple striation fingers appear to undergo a quasi-steady state $\underline{E} \times \underline{B}$ drift across the magnetic field $\underline{B}_o$. It is the latter issue of quasi-steady state solutions that we will address in this paper.

Dungey (1958) and later Perkins et al. (1973) showed that the coupled set of equations for density n and potential ϕ describing the dynamics of plasma clouds have no steady state solutions if the cloud, as described by n, has a finite size (with the gradient of n) in the two dimensions perpendicular to the magnetic field $\underline{B}_o$. An exception to this rule is a "waterbag" plasma cloud with a piecewise constant density profile with constant densities n_1 and n_2 inside and outside the plasma cloud, respectively (e.g., elliptic, circular cylindrical, slab plasma clouds). Linson (1972) solved the potential (ϕ) equation using methods such as those found in Smythe (1950). In this approach, the continuity equation for n is automatically satisfied. In this configuration, the induced electric field is constant inside the single waterbag plasma cloud and is anti-parallel to the external (zeroth order) electric field. Thus, the total field inside is reduced. A method similar to that of Linson's was adopted by Ossakow and Chaturvedi (1978) to study the morphology of rising equatorial spread F bubbles. In this case, the induced electric field is again constant inside the single waterbag plasma bubble but is parallel to the external field so that the total electric field inside is enhanced.

In a previous paper by Chen et al. (1983), hereafter referred to as Paper I, a nontrivial extension of the single bubble model of Ossakow and Chaturvedi (1978) was carried out to study a multi-bubble system. In Paper I, the method of image dipoles was developed to solve the potential equation analytically. In the presence of neighboring bubbles, it was found that the induced electric field inside the multiple waterbag bubbles is not constant and has components perpendicular as well as parallel to the external (zeroth order) electric field. This implies that the bubble contours would deform in the subsequent induced $\underline{E} \times \underline{B}$ drift motion and that no steady-state solution exists.

In Paper I, it was noted that the analytical solution obtained for bubbles (plasma density depletions) was also applicable to multiple clouds (plasma density enhancements) such as one might encounter in plasma cloud striation fingers. It was also shown that the interaction of the neighboring bubbles and clouds is substantial for $x_o/a \lesssim 3$ (where $2x_o$ is the center-to-center distance between two cylindrical bubbles and a is the radius of the cylinder). In particular, for the multi-bubble case, the induced $\underline{E} \times \underline{B}$ drift velocity is reduced by more than 20% to 40% as x_o/a is decreased from 3 to 1.5. At the same time, a horizontal drift of as much as 50% of the vertical drift (with equatorial F region geometry in mind) is produced and the drift velocity within bubbles can vary by 20% to 40%. This nonuni-formity in the field and in the induced $\underline{E} \times \underline{B}$ drift is reduced as x_o/a increases. However, even for $x_o/a \gtrsim 5$, the nonuniformity is still in the range of a few percent.

In the case of the multi-finger configuration, observations (see, for example, Davis et al., 1974) indicate that the late-time striation fingers typically have x_0/a in the range of 1.5 to 2.5. Thus, one important observational constraint on any possible quasi-steady state solution is that the electric field inside each cloud must be uniform even for separation distances x_0/a of 1.5 to 2.5, i.e., even in the regime where the inter-cloud electrical interaction is significant. It was already observed in Paper I that the nonuniformity in the multi-cloud configuration was less pronounced than in the multi-bubble configuration for the same separation distance. In this paper, we will show quantitatively that quasi-steady state solutions do exist for multiple plasma cloud striations even at small separation distances.

In section 2, we briefly review the theoretical formulation of two-cloud and multi-cloud configurations. In section 3, we present the detailed results of the above configurations. In Section 4 we give the summary and discussion.

2. THEORETICAL FORMULATION

In this paper, we consider the instantaneous electric field of a system consisting of a finite number of electrically interacting plasma density enhancements ("fingers") imbedded in a uniform background plasma and neutral gas. Neutral wind effects are not included. In Figure 1, two interacting clouds are shown schematically along with the coordinate system and the external electric and geomagnetic fields. The clouds ("fingers") are modeled by cylinders with circular cross-sections of radius a, and the center-to-center separation distance is $2x_o$. The axes of the cylinders are aligned with the earth's magnetic field ($B_o\underline{\hat{z}}$) which is assumed to be uniform. The clouds are immersed in a uniform ambient electric field $\underline{E}_o$ as indicated in Figure 1. For the present paper, we adopt the basic theoretical formulation of Paper I, utilizing the dielectric analogy to obtain the polarization induced electric field of the multi-finger system. We give below a brief summary of the relevant theoretical results as applied to F-region ionospheric plasma clouds and refer the reader to Paper I for a more comprehensive treatment and a list of references.

The basic equation describing the instantaneous polarization induced electric field, say, at t = 0, is

$$\underline{\nabla} \cdot (\sigma\, \underline{E}) = 0 \tag{1}$$

where

$$\sigma \equiv \nu_{in} \frac{nec}{B\Omega_i} \tag{2}$$

is the Pedersen conductivity for an F region plasma cloud. Equation (1) is equivalent to conservation of the cross-field plasma current arising from ion and electron drifts. The electric field $\underline{E}$ which drives the current consists of the uniform external field $\underline{E}_o$ and the polarization induced self-field. The electric field $\underline{E}$ satisfies the conditions across the cloud boundaries

$$\begin{aligned} (\sigma\, \underline{E})_{\perp} &= \text{continuous} \\ (\underline{E})_{\parallel} &= \text{continuous} \end{aligned} \tag{3}$$

and at infinity $(x,y \rightarrow \infty)$

$$\underline{E} \rightarrow \underline{E}_o. \tag{4}$$

The symbols $\parallel$ and $\perp$ refer to the directions parallel and perpendicular to the boundary surfaces, respectively. The above dielectric analogy was noted by Longmire (1970) and Perkins et al. (1973).

In Paper I, we developed the method of image dipoles to solve equation (1) exactly, subject to the conditions (3) and (4). In the interest of keeping the paper self-contained, we repeat the salient results (equations (17), (18), (22) and (23) of Paper I). For the two-cloud system, the total electric field outside the cylindrical clouds has components

$$E_x = -E_o + \sum_{n=0}^{\infty} 2P_n\left[f(x + x_n,y) + f(x - x_n,y)\right], \tag{5}$$

and

$$E_y = \sum_{n=0}^{\infty} 2P_n\left[h(x + x_n, y) + h(x - x_n, y)\right], \tag{6}$$

The total electric field $\underline{E}^*$ inside the cloud centered at $x = x_o$ has the components

$$E_x^* = \frac{2}{1+K}\left[- E_o + \sum_{n=0}^{\infty} 2P_n f(x + x_n, y)\right], \tag{7}$$

and

$$E_y^* = \frac{2}{1+K} \sum_{n=0}^{\infty} 2P_n h(x + x_n, y), \tag{8}$$

where the functions f and h are defined as

$$f(x,y) \equiv \frac{x^2 - y^2}{(x^2 + y^2)^2} ,$$

and

$$h(x,y) \equiv \frac{2xy}{(x^2 + y^2)^2} .$$

For $n \neq 0$, we have

$$P_n \equiv - \left(\frac{1-K}{1+K}\right) \frac{a^2}{b_n^2} P_{n-1},$$

$$b_n \equiv x_o + x_{n-1}$$

and

$$x_n \equiv x_o - \frac{a^2}{x_o + x_{n-1}} .$$

For $n = 0$, we have $x_n = x_o$ and $P_n = P_o$ where

$$P_o \equiv \frac{1}{2} \left(\frac{1-K}{1+K}\right) a^2 E_o . \tag{9}$$

Here,

$$K \equiv \frac{\sigma_1}{\sigma_2} \tag{10}$$

where σ_1 and σ_2 are the Pedersen conductivities inside and outside the clouds, respectively. In reality, the collision frequency ν_{in} and the number density n vary along the magnetic field so that the conductivity ratio K should be redefined in terms of flux-tube integrated quantities. For the cylindrical cloud centered at $x = - x_o$, the inside field is obtained by replacing x_n with $- x_n$ in the functions f and h. For a $N > 3$ system, a parallel calculation based on the same theoretical formulation yields series expressions similar to equations (5) through (8). Because they are extremely cumbersome and give no new insight, we will show only the results of the two and three cloud systems in this paper. Also, we will present detailed results only for $N = 2$ and $N = 3$ cases since Paper I has shown that $N > 5$ systems exhibit no significant quantitative or qualitative differences from the $N = 3$ case.

3. QUASI-STEADY STATE MULTI-CLOUD CONFIGURATION RESULTS

Equations (5) through (8) and the corresponding equations for a three-cloud system describe the electric field in the frame moving with the velocity $c\underline{E}_o \times \underline{B}_o/B^2$ relative to the earth. As a result of the polarization electric field, the plasma clouds undergo induced $\underline{E} \times \underline{B}$ drift motion with respect to the undisturbed ionosphere. If we define

$$\underline{\hat{E}} \equiv \underline{E}^* - \underline{E}_o, \tag{11}$$

then the relative drift velocity is

$$\underline{V} = c\,\frac{\underline{\hat{E}} \times \underline{B}_o}{B_o^2}\,. \tag{12}$$

Here, $\underline{E}_o = -E_o\underline{\hat{x}}$. In particular, the $\underline{E} \times \underline{B}$ drift velocity $\underline{V}_1$ of a single isolated cloud is given by

$$V_1 = -\left(\frac{1-K}{1+K}\right)\frac{cE_o}{B_o}\quad, \tag{13}$$

For plasma clouds, $K > 1$ and $\underline{V}_1$ is downward toward the earth (in an equatorial ionospheric configuration). This equation also shows that the plasma elements inside an isolated cloud drift uniformly, maintaining its geometrical shape. Thus, it is a steady-state configuration. Figure 2 shows the field lines corresponding to $\underline{\hat{E}}$ given by equation (11). Inside the cloud, the field and hence the $\underline{\hat{E}} \times \underline{B}$ drift are uniform while the field outside the cloud is that of a dipole $\underline{P}_o$ (equation (9)) located at the center of the circle.

In Figures 3(a), (b) and (c), we show a two-cloud *configuration with* the separation distance $x_o/a = 1.25$ *for* three values of the conductivity ratio K. This separation distance is smaller than the typical multi-finger situation where x_o/a is roughly 1.5 to 2.5 (see, for example, Davis et al., 1974). In fact, for $x_o/a < 1.25$, it may be observationally difficult to identify the adjoining clouds as separate. This separation distance is shown in order to maximize the effect of the inter-cloud interaction. Moreover, the $K = 3$ case is shown primarily because this value corresponds to the maximum inter-cloud influence for a given x_o/a. This can be seen by noting that each term in the series in equations (7) and (8) contains a power of the factor $(1-K)/(1+K)^2$. For $K > 1$, the absolute value of this quantity has a maximum at $K = 3$. Thus, Figure 3(a) represents the largest nonuniformity in the inside electric field for $x_o/a = 1.25$. As K increases, the nonuniformity decreases as shown by Figures 3(b) and (c). As a general remark, K is taken to be of the order of 10 for artificial barium clouds and is taken to be of the order of 100 or greater for nuclear clouds.

In Table 1, we show the numerical values of the two-cloud $\underline{E}_o \times \underline{B}_o$ direction drift velocity V (equation (12)) normalized to cE_o/B_o, along with the values of $V_s \equiv -(1-K)/(1+K)$, the normalized drift velocity (see equation (13)) of an isolated cloud. For $x_o/a = 1.25$, the $K = 3$ case exhibits a variation in V of up to 30% inside the clouds.This variation (i.e., nonuniformity) decreases as K increases. For $K = 10$, the variation is roughly 10% and for $K = 100$, it is 1%. In addition, V approaches the single-cloud value V_s as K increases. Thus, we conclude that, even for a small separation distance of $x_o/a = 1.25$, $K = 100$ is nearly indistinguishable from the single-cloud case. It is of importance

TABLE 1. NORMALIZED $(\underset{\sim}{E}_o \times \underset{\sim}{B}_o)_y$ DRIFT VELOCITIES FOR A TWO-PLASMA CLOUD SYSTEM. $V_s = -(1-K)/(1+K)$ IS THE INDUCED DRIFT VELOCITY FOR THE SINGLE CLOUD CASE

x_o/a	K	A	B	C	V_s
1.25	3	0.3699	0.4548	0.4772	0.5000
	10	0.7316	0.7889	0.8035	0.8181
	100	0.9682	0.9762	0.9782	0.9802
1.5	3	0.4321	0.4701	0.4833	0.5000
	10	0.7755	0.7995	0.8077	0.8181
	100	0.9744	0.9777	0.9788	0.9802
2.0	3	0.4722	0.4844	0.4900	0.5000
	10	0.8016	0.8089	0.8122	0.8181
	100	0.9780	0.9790	0.9794	0.9802

to note from Figures 3(a), (b) and (c) that the outside field is significantly distorted from the single-cloud dipolar field and that the distortion does not change appreciably as K is increased. This implies that the intrinsic inter-cloud interaction is not weakened as K is increased and that only the inside field is affected.

Figures 4(a), (b) and (c) and Figures 5(a), (b) and (c) show two-cloud systems with $x_o/a = 1.5$ and $x_o/a = 2.0$, respectively. Again, three values K = 3, 10 and 100 are shown for each value of x_o/a. As x_o/a increases, the inter-cloud interaction decreases. As a result, the inside field is nearly uniform even for K = 3. In particular, for $x_o/a = 2.0$ which is a typical separation distance between striations in late times, Table 1 shows that K = 10 case has a field variation of roughly 1% and the K = 100 case has a variation of 0.1% inside the clouds. In addition, the deviation of the drift velocity from that of the single-cloud case is roughly 1% or less. Such a system of multi-clouds would $\underline{E} \times \underline{B}$ drift in unison while each cloud would maintain its geometrical shape.

Similar behavior is true for the three-cloud and larger N-cloud systems. In particular, Figures 6, 7 and 8 show three-cloud systems with $x_o/a = 1.25$, 1.5 and 2.0, respectively. For each value of x_o/a, three values of K are shown, viz. K = 3, 10 and 100. In general, the field inside the outer clouds tends to be slightly more nonuniform in magnitude than that in the central cloud. On the other hand, the field in the central cloud tends to be slightly weaker than that in the outer clouds so that the outer clouds drift downward shomewhat faster than the central clouds. However, the slight nonuniformity and inequality both decrease with increasing K and vice versa.

Table 2 shows that, for $x_o/a = 1.25$, the variation in the outer cloud decreases from 35% for K = 3 to 12% for K = 10 and to 1.3% for K = 100 while the variation in the central cloud ranges from 19% for K = 3 to 6% for K = 10 and to 0.1% for K = 100. As x_o/a increases, the nonuniformity throughout all the clouds decreases. At $x_o/a = 2.0$, the variation in the field is typically less than 1% for K = 10 and K = 100. Figures 7(a), (b) and (c) and Figures 8(a), (b) and (c) show the above behavior. Again, as K increases, the drift velocity V inside each cloud approaches that of an isolated cloud, V_s.

We conclude that multi-finger quasi-steady solutions do exist even for small separation distances if K is made sufficiently large. In particular, for $x_o/a = 2.0$, multi-fingers with K = 10 and K = 100 both constitute quasi-steady state configurations for all practical purposes. Observationally, these systems would be seen to drift across the magnetic field in unison without changing their cross-sectional shapes.

The reason for the quasi-steady state behavior is easy to understand by examining equations (7) and (8). The electric field which determines the relative $\underline{E} \times \underline{B}$ drift motion of the clouds is given by equation (11). Therefore,

$$\tilde{E}_x = -\left(\frac{1-K}{1+K}\right) E_o + \frac{2}{1+K} \sum_{n=0}^{\infty} 2P_n f(x + x_n, y)$$

From the expressions of P_n and P_o (equation (9)), we see that P_n and P_o are not sensitive to K for large K since the factor (1-K)/(1+K) is nearly equal to -1. However, the factor 2/(1+K) multiplying the series in the above expression and in equation (8) is nearly equal to 2/K so that the contributions from the neighboring clouds are reduced by a factor of K^{-1}

and, for $K \rightarrow \infty$, $\tilde{E}_x$ approaches the single-cloud value $-E_o(1-K)/(1+K)$ with $\tilde{E}_y \rightarrow 0$. Physically, the cloud with a large K is analogous to a dielectric with a large dielectric constant (see Paper I). Note also that the outside field (equations (5) and (6)) depends only on (1-K)/(1+K). As a result, the outside field is not sensitive to K for large K as has been demonstrated by Figures 3 through 8.

TABLE 2. NORMALIZED $(\underline{E}_o \times \underline{B}_o)_y$ DRIFT VELOCITIES FOR A THREE PLASMA CLOUD SYSTEM. $V_s = -(1-K)/(1+K)$ IS THE INDUCED DRIFT VELOCITY FOR THE SINGLE CLOUD CASE.

x_o/a	K	A	B	C	D	E	V_s
1.25	3	0.4069	0.3419	0.3450	0.4405	0.4678	0.5000
	10	0.7560	0.7104	0.7116	0.7781	0.7905	0.8181
	100	0.9715	0.9703	0.9651	0.9746	0.9772	0.9802
1.5	3	0.4391	0.4137	0.4183	0.4612	0.4769	0.5000
	10	0.7395	0.7631	0.7655	0.7932	0.8034	0.8181
	100	0.9750	0.9727	0.9730	0.9768	0.9782	0.9802
2.0	3	0.4673	0.4604	0.4650	0.4792	0.4861	0.5000
	10	0.7981	0.7939	0.7965	0.8053	0.8096	0.8181
	100	0.9775	0.9770	0.9773	0.9784	0.9790	0.9802

4. SUMMARY AND DISCUSSION

In this paper, we have described the morphology of two-plasma cloud and three-plasma cloud configurations, embedded in an F region ionosphere, in detail using the techniques developed in Paper I. The results are applicable to larger N-plasma cloud systems to a good approximation. The primary objective of this paper is to demonstrate the existence of quasi-steady state multi-plasma cloud configurations in which the electric field inside all the clouds is essentially uniform and equal so that such systems would be seen to drift in unison across the magnetic field while maintaining the overall geometrical shapes.

We have shown that the influence of neighboring clouds on the electric field inside the clouds decreases as K^{-1} for any x_o/a so that the cloud interior is effectively "shielded" from the inter-cloud interactions. Thus, if there is an array of cylindrical clouds with circular cross-sections, each one of which has uniform polarization induced electric field in the absence of neighboring clouds, then the electric field inside each cloud approaches the uniform field of an isolated cloud in the limit as $K \rightarrow \infty$ for any $x_o/a > 1$.

In particular, for $K = 10$, a typical value for barium clouds, the nonuniformity in the magnitude of the drift velocity is approximately 10% for $x_o/a = 1.25$. The drift velocity is also reduced from V_s by approximately 10%. As x_o/a is increased to 2.0, the nouniformity is reduced to approximately 0.1% and the magnitude of V is also reduced from V_s by a small fraction of 1% (see Tables 1 and 2). Thus, for high-K multi-plasma clouds, deviations from complete uniformity (i.e. an exact steady state configuration) are practically imperceptible.

It has been conjectured (N. Zabusky and E. Overman, 1983, private communication) that one can obtain steady-state solutions for multi-cloud systems by adjusting the contour of each cloud. One cross-section suggested is an ellipse. However, the underlying reason for the quasi-steady state solutions obtained in this paper is the K^{-1} "shielding" effect exhibited by high-K clouds. In fact, since isolated elliptic cross-sections are known 1978) to correspond to steady state configurations (Ossakow and Chaturvedi, 1978), we expect an array of clouds with the same elliptic cross-sections to undergo quasi-steady state $\underline{E} \times \underline{B}$ drift motion if the Pedersen conductivity ratio K is large.

It is not too far-fetched to use a cylindrical waterbag model for evolving plasma clouds and their associated striations. Linson (1972) has shown that evolving (steepening) barium clouds tend to obey a cylindrical rather than a sheet-like model. Also, the results from numerical simulations of steepening equatorial spread F bubbles (with distributed density) show that, at late times, they are best modeled by cylindrical waterbag models (see Ossakow and Chaturvedi, 1978; Ossakow et al., 1979). In the real plasma cloud and attendant striation phenomena, there are continuous plasma density profiles, which subsequently steepen on their backside. As they steepen, at late times, they look like waterbags, except in a thin shell. Thus, the approximation of circular cross sections with piecewise constant density profiles for plasma cloud striation fingers is expected to be applicable in the nonlinear regimes (late times).

ACKNOWLEDGMENT

This research was supported by the Defence Nuclear Agency and the Office of Naval Research.

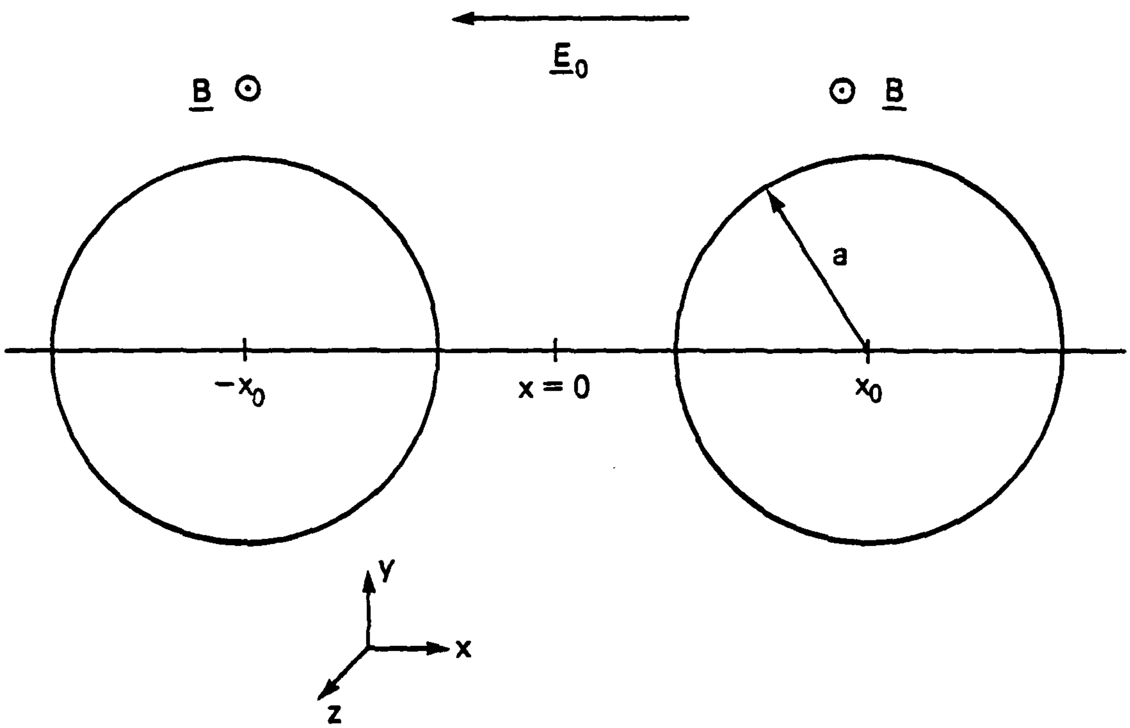

Fig. 1 A schematic drawing of two plasma density enhancements ("clouds") and the coordinate system. The clouds have circular cross-sections of radius a and are infinite in extent along the z direction.

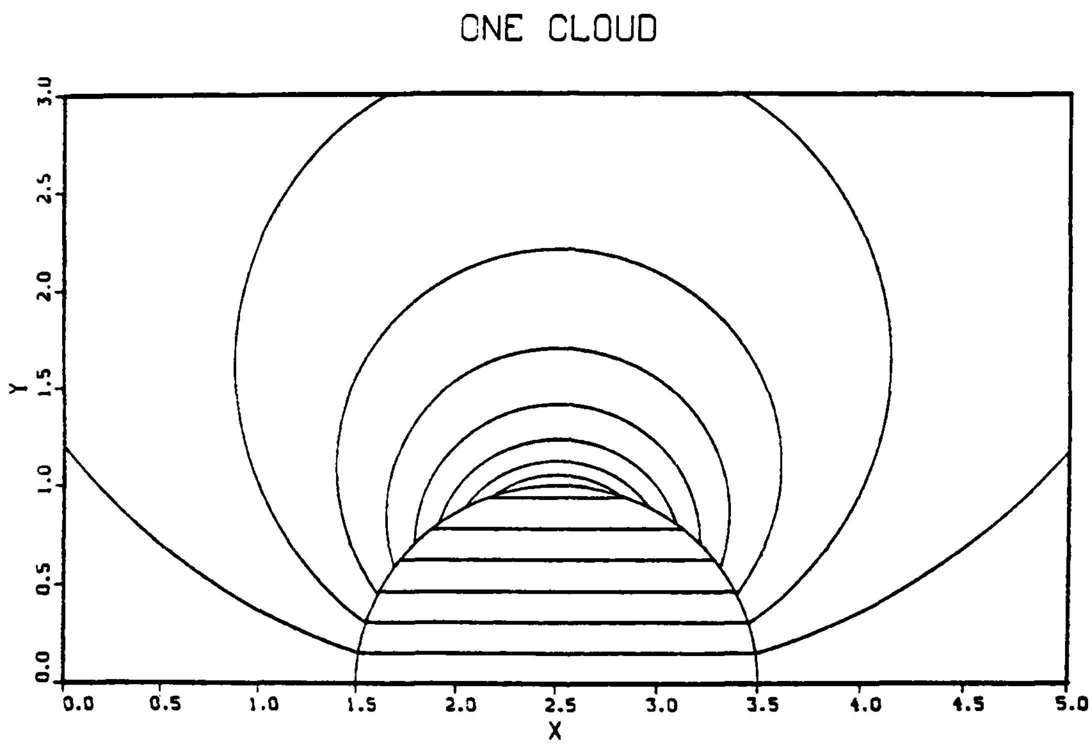

Fig. 2 The field line configuration of $\grave{\underline{E}}$ (equation (11)) for an isolated cloud. $\grave{\underline{E}}$ is uniform inside the cloud and dipolar outside. The cloud drifts according to equation (12).

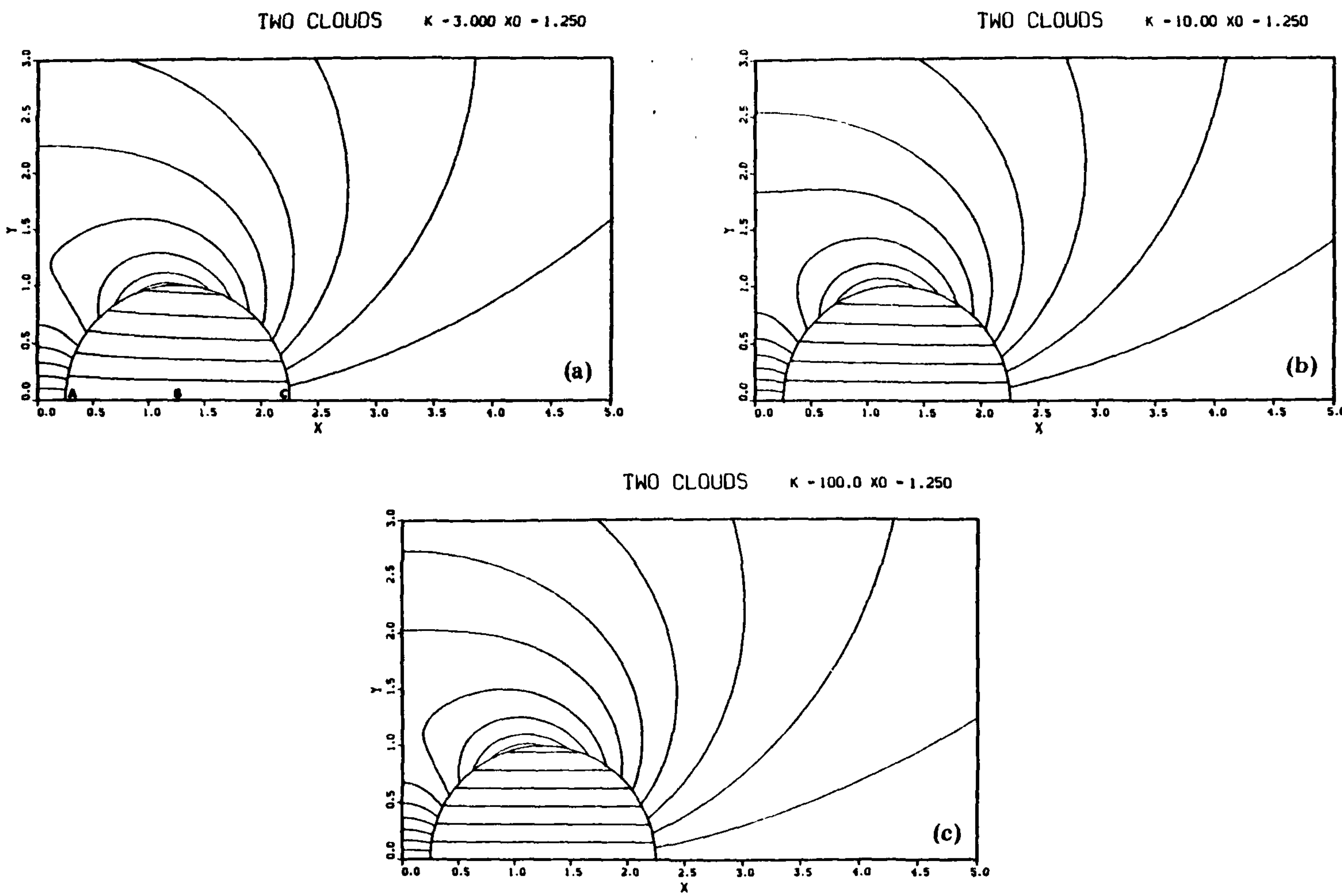

Fig. 3 The configuration of the electric field $\underline{\tilde{E}}$ (equation (11)) in a two-cloud system with $x_o/a = 1.25$ for (a) K = 3, (b) K = 10 and (c) K = 100.

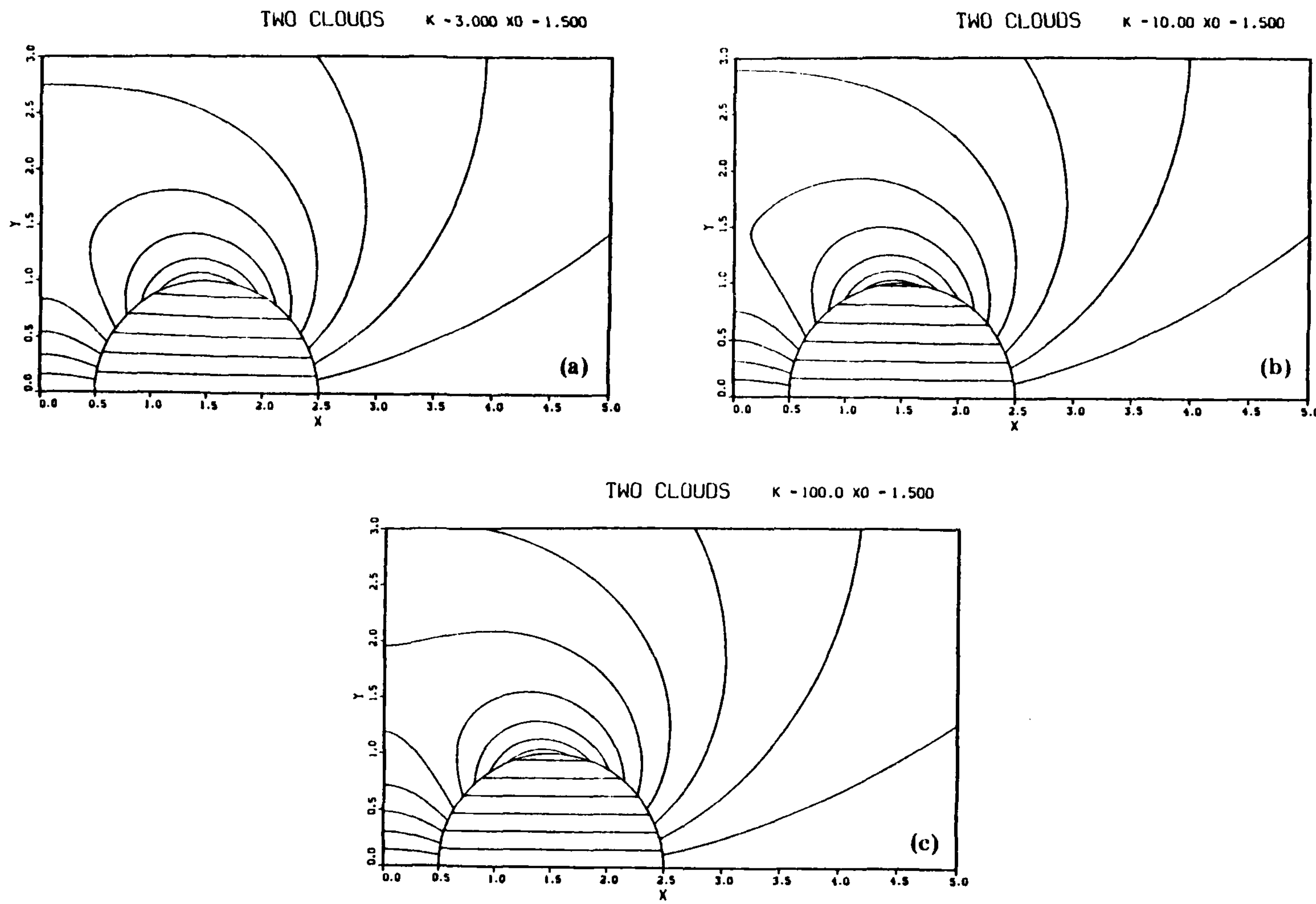

Fig. 4 The configuration of the electric field $\underline{\tilde{E}}$ (equation (11)) in a two-cloud system with $x_o/a = 1.5$ for (a) K = 3, (b) K = 10 and (c) K = 100.

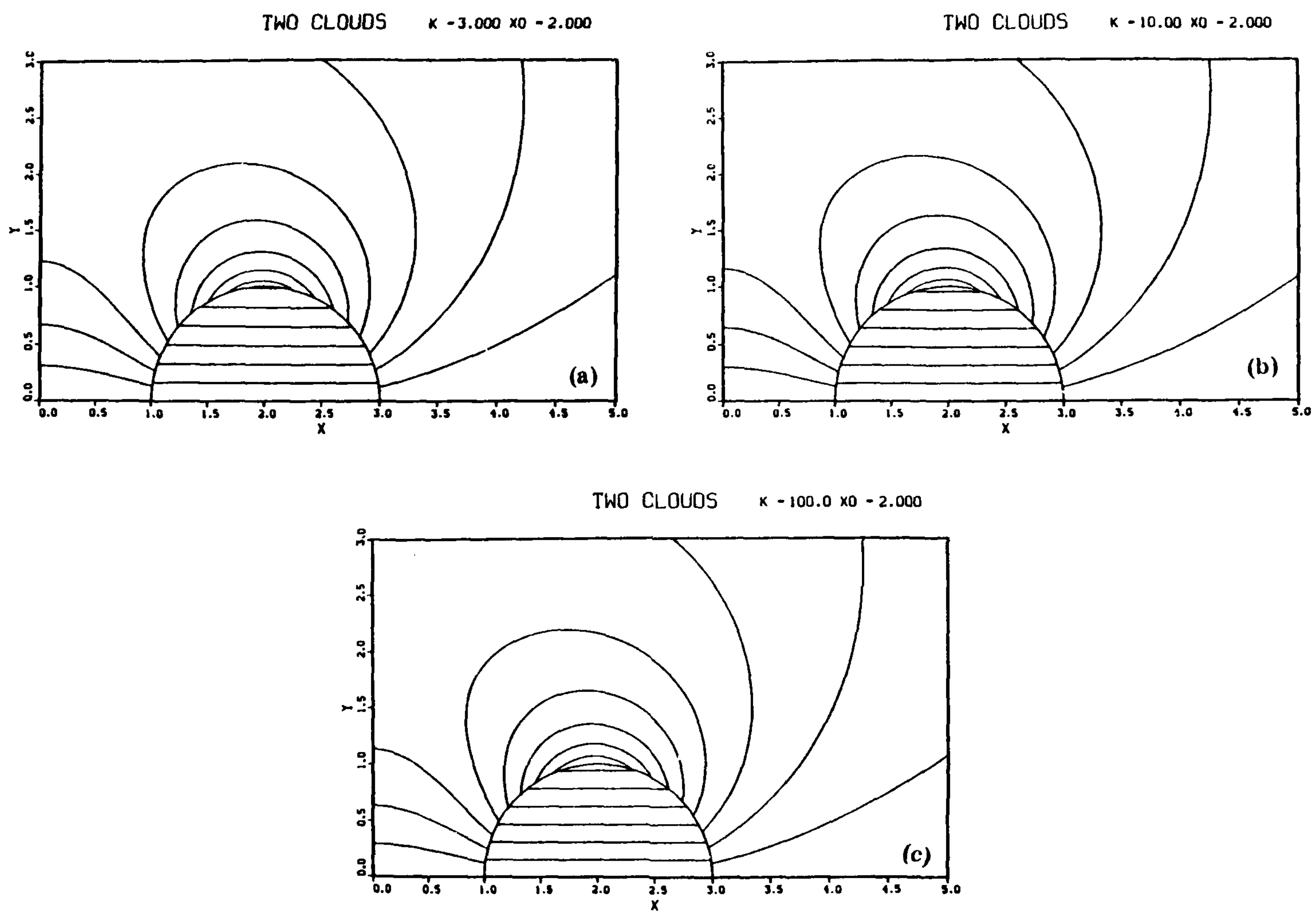

Fig. 5 The configuration of the electric field $\underline{\tilde{E}}$ (equation (11)) in a two-cloud system with $x_o/a = 2.0$ for (a) K = 3, (b) K = 10 and (c) K=100.

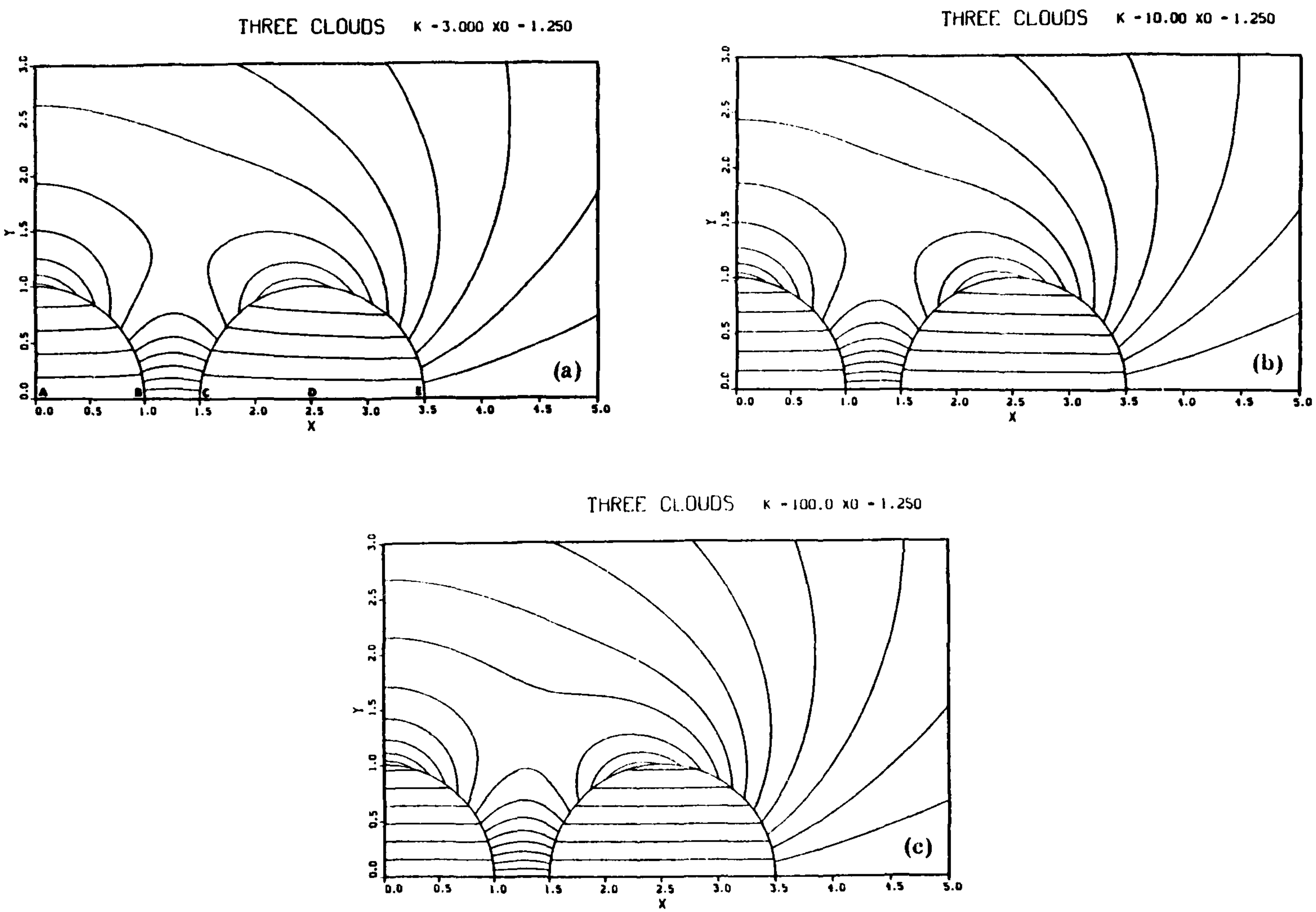

Fig. 6 The configuration of the electric field $\check{\underline{E}}$ (equation (11)) in a three-cloud system with $x_o/a = 1.25$ for (a) K = 3, (b) K = 10 and (c) K=100.

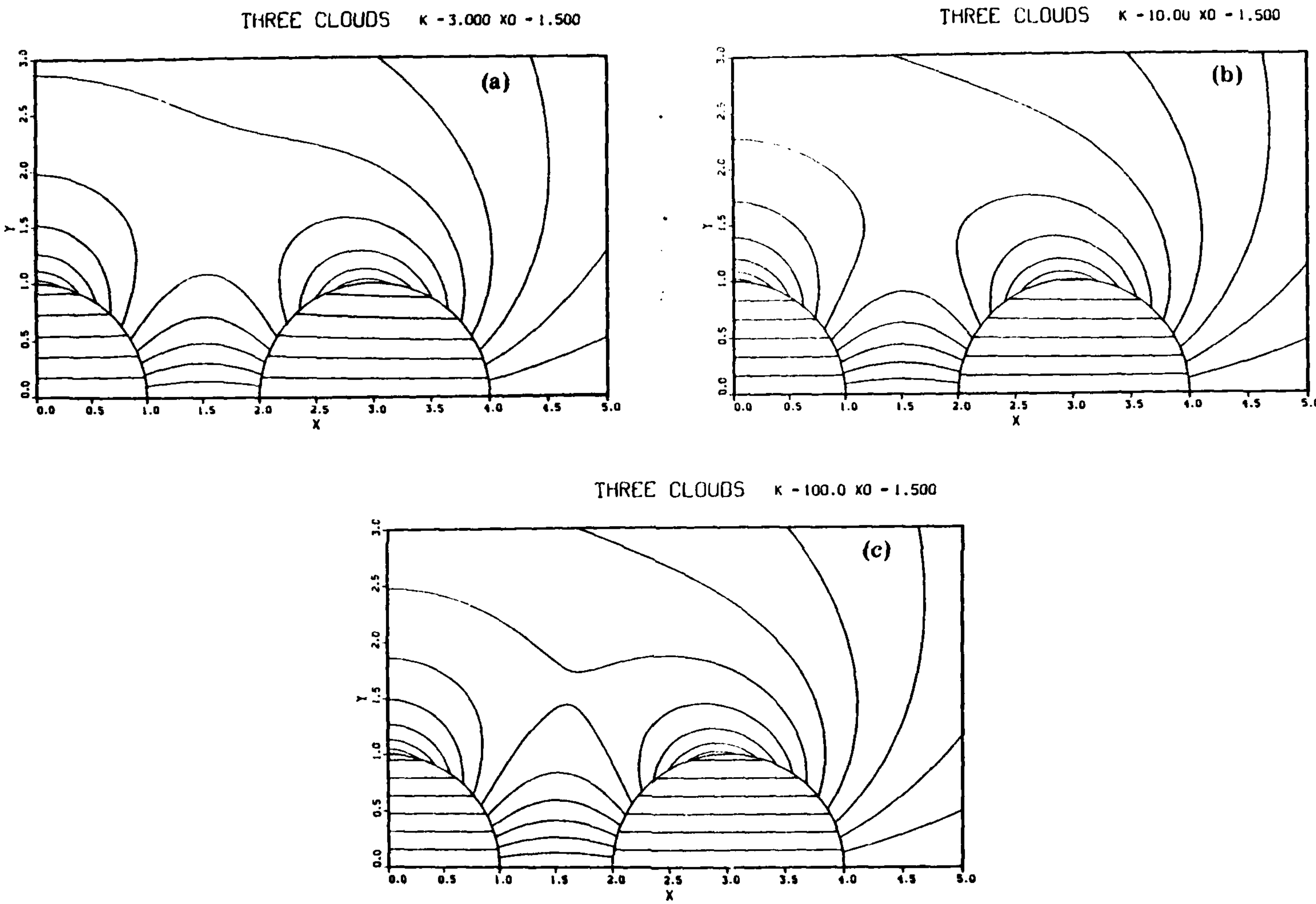

Fig. 7 The configuration of the electric field $\tilde{\underline{E}}$ (equation (11)) in a three-cloud system with $x_o/a = 1.5$ for (a) K = 3, (b) K = 10 and (c) K = 100.

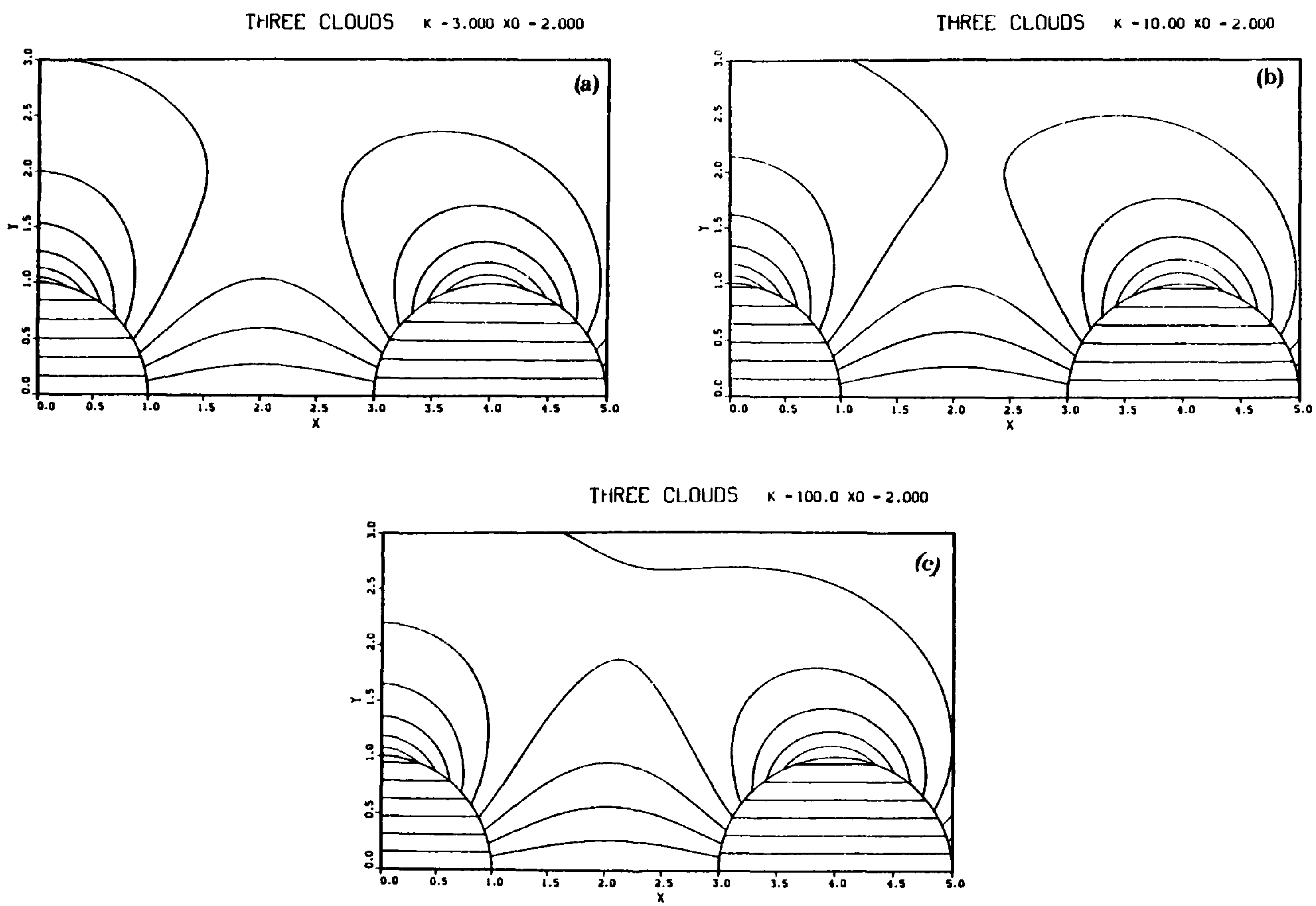

Fig. 8 The configuration of the electric field $\underline{\tilde{E}}$ (equation (11)) in a three-cloud system with $x_o/a = 2.0$ for (a) K = 3, (b) K = 10 and (c) K = 100

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